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BINOCULAR FUSION TIME IN SLEEP-DEPRIVED SUBJECTS

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I. Introduction.

The time required for the attainment of binocular single vision when the gaze is changed from one distance to another is a component of total reaction time and may be critical at the closing speed of modern aircraft on collision courses. When diplopia is prismatically induced binocular fusion time is reported to be increased by alcohol ingestion[3], drugs and fatigue[4], and age[6]. This report deals with binocular fusion time in six subjects fatigued by 86 hours of sleep deprivation.

II. Methods.

Six pairs of paid subjects, all less than 30 years of age and with good binocular vision, were studied; one subject in each pair was kept awake continuously for 86 hours while the other subject maintained a normal sleep/wakefulness regime and served as a control. Measurements of binocular fusion time were made each morning and evening throughout the experimental period. The subjects were allowed food, water, soft drinks, tobacco and de-caffeinated coffee *ad libitum.* Wakefulness was assured by a 24-hour watch maintained by project investigators. Recreational facilities (pool table, pin ball machines, painting equipment, TV, etc.) were available for the exclusive use of the subjects to aid in maintaining wakefulness. Control subjects were treated the same as sleep-deprived subjects except that they were allowed to sleep through each night in the CAMI clinic.

Briefly stated, the procedure for determining binocular fusion time was modified from that originally described by Brecher[2], and involved the presentation of a light steadily to the left eye and interruptedly to the right eye. The light source was situated in the center of a blackboard that was marked off into five cm squares. Interrupted presentation of the light was accomplished by a cylindrical shutter rotating at 2.5 rps. Crossed Risley rotary prisms positioned in front of the shutter allowed the image in the right eye to be positioned as desired. Measurements were made at six image positions, one, two, and three squares left and right. Any hyper- or hypophoria was eliminated by appropriate prismatic adjustment and all measurements were made with the subjects' eyes located six meters from the light source. Under these conditions, the prismatically-induced diplopia initiated a reflex attempt to fuse the two images. The interrupted presentation of the target slowed the fusional process so that it could be accurately measured. The subject controlled the process by means of a single button that, when pressed, opened an occluder shutter positioned between his eye and the constantly running cylindrical shutter and simultaneously started an electric timer. When he perceived one image, he simply released the button, thus closing the occluder and stopping the clock. The details of the method have been previously published[6].

Some learning is involved on the part of the subject in the operation of the apparatus and in perception of the fusional process. Thus, on the morning of the first day the subjects were tested until their fusion times became consistent and they could easily detect the extent and direction of image displacement. Their initial binocular fusion times were then determined. It is probable that some learning continued throughout the five-day period. Since this study was secondary to a larger study it was not possible to have the subjects in the laboratory long enough to be assured that they were on the final plateau of their learning curves.

III. Results.

Sleep deprivation had no pronounced effect on the binocular fusion reflex as far as fusion time was concerned (Fig. 1, Tables 1–3). Five of the sleep-deprived subjects showed shorter fusion times at the end of the 86-hour sleepless period than at the beginning of the experiment and

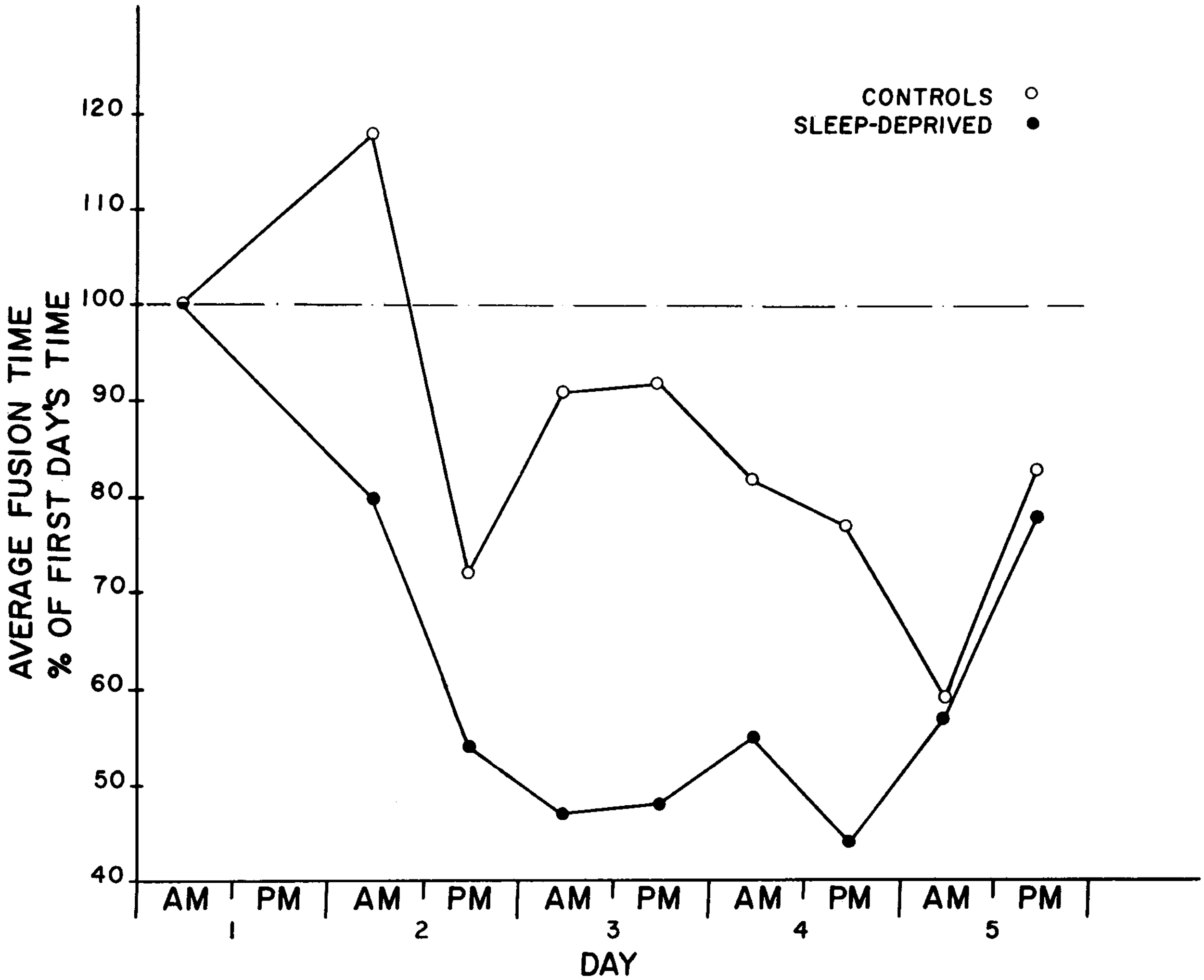

FIGURE 1. Graph of Average Fusion Times of the Two Groups in Percent of Initial Value for Each Period.

four of the control subjects showed improved fusion times. Figure 1 is a graph of average fusion times of the two groups expressed in percent of the initial value for each observational period. The image displacement represented by this graph is two squares to the left, so chosen because it represented a fusional task of intermediate difficulty that was accomplished by all of the subjects except for one control subject (No. 8). It shows steady improvement of fusional ability by both groups over the five-day period with the sleep-deprived group out-performing the control group. Both groups finished the experiment with average fusion times below the initial value.

Figure 2 is a group of graphs representing the average fusion times of each subject for two squares to the left for each observational period. No differentiation between the groups is suggested. The one control subject (solid lines) with such high and erratic values must not be considered as significant. That subject was erratic in the other experiments, also, and exhibited a great deal of anxiety and general confusion with inappropriate responses in conversation and concern for himself as an experimental subject.

The rationale was adopted that, if fatigue induced by sleeplessness caused an increase in fusion time, the fusion time at the end of the experiment should be the longest. Table 1 is made up of the ratios of the initial fusion times to the fusion times at the end of 86 hours. Thus, values in the table that are greater than unity indicate that the terminal fusion time was less than the initial. All of the group averages are greater than unity. Because of the fact that some of the fusion times are infinite (no fusion), statistical treatment of the values is not feasible.

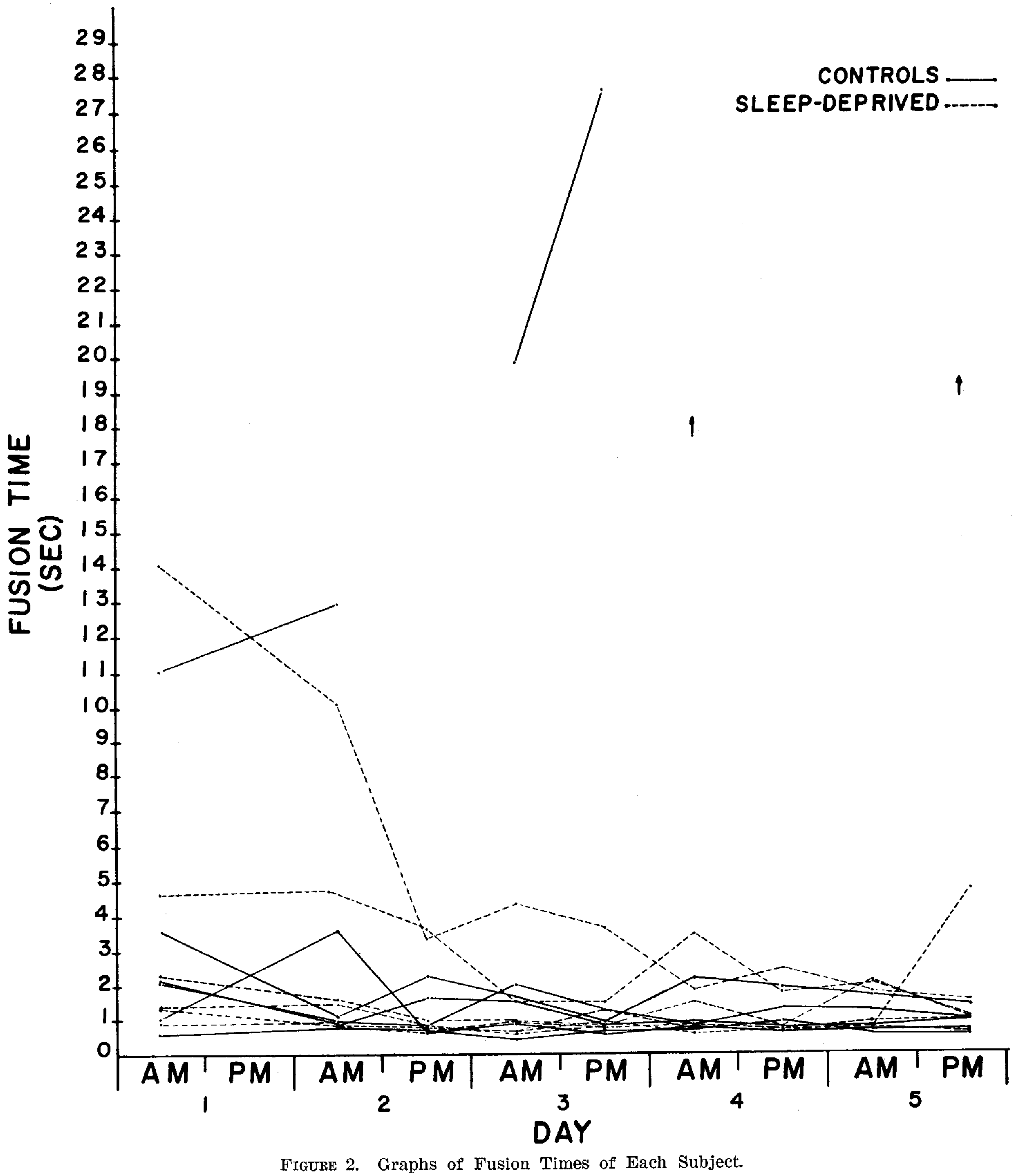

FIGURE 2. Graphs of Fusion Times of Each Subject.

Table 2 is composed of ratios of the fusion times on the morning of each day to the afternoon of each day. Sixty percent of the controls and 79 percent of the sleep-deprived subjects had faster fusion times in the afternoons than in the mornings.

Table 3 is similar to Table 2, except that the ratios were obtained by dividing each afternoon's fusion time by the fusion time measured the next morning. Seventy percent of the controls' values on next morning were less than the values on the previous afternoon. Tables 2 and 3, taken together, indicate that fusion time progressively speeded up over the 86-hour period in both control and sleep-deprived groups.

One observation made at the time of the fusion time determinations is not reflected in the data and must be prefaced with the following explanation. The apparatus used in this study allows

TABLE I.—Fusion Time First Day/Fusion Time Last Day

SLEEP DEPRIVED

Subject No.	Squares Displacement Left 1	2	3	Squares Displacement Right 1	2	3
1	1.1	4.3	1.4	0.6	0.6	5.7/NF*
2	1.2	1.4	1.6	1.2	0.4	0.4
3	8.0	8.8	17.1	4.5	9.1	12.8
4	0.4	0.4	0.2	1.6	2.4	1.3
5	0.7	1.4	1.2	1.0	1.0	1.5
6	0.8	2.9	2.0	0.7	NF/NF	NF/NF
Av.	2.0	3.0	1.3	1.6	2.7	4.0
CONTROLS						
7	1.8	2.5	4.4	3.2	1.5	NF/6.5
8	0.6	0.6	NF/NF	0.2	NF/NF	NF/NF
9	1.3	0.9	0.7	1.5	1.1	1.3
10	3.0	1.6	1.7	1.4	NF/NF	6.4/NF
11	1.0	1.4	0.7	1.8	1.7	0.9
12	1.0	2.2	2.1	1.3	1.2	NF/1.8
Av.	1.5	1.5	1.9	1.6	1.4	1.1

*NF=No Fusion.

TABLE II.—Fusion Time Each A.M./Fusion Time Each P.M.

(2nd Square Left Only)

SLEEP DEPRIVED

Day*

Subject No.	2	3	4	5
1	1.3	1.2	1.9	1.9
2	1.1	1.2	1.2	1.2
3	3.0	1.2	0.7	1.4
4	1.3	0.7	1.0	0.2
5	1.6	0.8	1.0	0.9
6	1.6	1.1	1.7	2.9
Av.	1.7	1.0	1.3	1.4
CONTROLS				
7	0.5	1.3	1.2	1.1
8**	---	---	---	---
9	1.1	0.7	0.7	0.9
10	1.2	1.6	0.5	1.0
11	5.4	1.4	1.1	0.9
12	0.5	1.8	1.2	0.8
Av.	1.7	1.4	0.9	0.9

*First day omitted because schedule did not permit a P.M. determination.

**Subject failed to accomplish fusion.

TABLE III.—Fusion Time P.M. Each Day/ Fusion Time A.M. Next Day

(2nd Square Left Only)

SLEEP DEPRIVED

P.M. Day/A.M. Day

Subject No.	2/3	3/4	4/5
1	2.1	0.4	0.8
2	0.8	0.9	0.9
3	0.8	2.0	1.1
4	1.0	1.4	1.0
5	1.5	1.1	0.8
6	1.0	0.6	0.4
Av.	1.2	1.1	0.8
CONTROLS			
7	1.4	0.6	1.2
8**	---	---	---
9	1.5	1.0	1.6
10	0.4	1.5	1.3
11	0.8	0.8	1.1
12	1.1	1.0	1.0
Av.	1.0	1.0	1.2

*Ratio for Day 1/Day 2 omitted because schedule did not permit a P.M. determination on Day 1.

**Subject failed to accomplish fusion.

an image to be placed anywhere on the retina of the right eye and does not cause any axis deviation. That is to say, the subjects' resting phoria was present throughout the experiment. That heterophoria apparently varied slightly from time to time, necessitating a readjustment of the Risley prisms to position the light source at the desired place on the grid. When the subject first sat down, a "try and see" method of adjustment was used to arrive at the desired image placement. In the fatigued subjects toward the end of the experiment, the image became extremely difficult to set. The experimenter would think that the light was properly positioned only to have the subject report upon beginning the determination that the light had moved or that it had disappeared entirely. Upon several occasions the subjects' heterophoria became so variable that attempts to obtain a stabilized image placement had to be abandoned.

IV. Discussion.

The lack of effect of sleeplessness on the binocular fusion reflex should not be taken to mean that the sleep-deprived subjects in this experiment were not fatigued. At times toward the end of the sleepless period, some of the subjects hallucinated. One tried to pick up the painted parking space lines in a parking lot; another made an elaborate detour around an imagined roll of barbed wire on the sidewalk. In all probability, three factors operated to contribute to lack of measureable effect; (1) the resistance of the reflex to fatigue and (2) the ability of the subjects to "muster their reserves" for the brief period of the determination. A third factor, obviously, is that when a subject became so erratic that the target could not be set, no measurements were made and no data were acquired.

Brecher, et al.[4] also found heterophoria to change during fatigue. These workers, however, reported that the binocular fusion reflex failed after about 30 hours of sleeplessness. They further reported that the fusion reflex failed first at an observation distance of 33 cm, then at 82 cm and last at 6 meters, indicating that the reflex was more difficult to maintain when more convergence was called for.

The slowed binocular fusion technique has been compared with an objective cinematographic technique and it was claimed that good correlation existed[1]. However, neither method measured "natural" fusion time which would apply when a person regarded a scene containing objects at different distances. Therefore, conclusions drawn from the results of this study regarding the ability of extremely fatigued subjects to accomplish or maintain fusion under natural conditions must be made with caution. The slowed binocular fusion time method is merely one test for the strength of a reflex under one set of conditions. It is a particularly useful method when a series of measurements are to be made on the same person, thus showing a trend if such is present.

Such a trend was apparently shown by both groups, in the direction of improvement of rate of binocular fusion. This result could have been caused by the orthoptic training inherent in the procedure or by some more subtle learning process. Suffice it to say, however, that fatigue did not prevent the improvement. This finding is consistent with the results of the other study that was concurrently executed, that the regulation of body temperature and the excretion of catecholamines, magnesium and creatinine were unaffected significantly by sleep deprivation[5].

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